Integrated Temperature and Humidity Control – A Unique Approach

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ABSTRACT

During hot and humid periods, a comfortable indoor environment can be attained only by controlling both the dry-bulb temperature and the humidity in the space. Conventional thermostats control the ON/OFF status of a cooling plant to maintain only the dry-bulb temperature within the conditioned space. This can result in the space dew-point temperature increasing to uncomfortable levels, especially during cool and humid times of the day and/or when there is high latent gain. Consequently, the occupant must resort to undesirable and inefficient interventions (e.g., manually lowering the space dry-bulb temperature set point) to "sweat out" the water from the air. An innovative controller, the Integrated Temperature and Humidity Controller, has been invented for controlling both the dry-bulb temperature and the absolute moisture content of the air in a conditioned space. These new algorithms have been implemented in a product prototype, and limited field tests have been performed. Preliminary results confirm the expected operation and performance of the controller and its robustness and are extremely encouraging.

INTRODUCTION

To maintain a comfortable indoor environment, particularly during hot and humid periods, it is important to control not only the dry-bulb temperature but also the humidity in the space. Since conventional controllers (thermostats) are of the dry-bulb type in that they control the ON/OFF status of the air conditioner to maintain only the dry-bulb temperature within the conditioned space, the moisture content (i.e., the humidity) of the air within the room, and hence the dew-point temperature, can increase to uncomfortable levels, especially during cool and humid times of the day and/or when there is high internal latent/moisture gain (e.g., from showers, baths, cooking, washing). An example of a cool and humid time of day is the late evening/night through morning hours, during which the sensible thermal load experienced by the conventional thermostat could be negligible, resulting in very few cooling plant operations.

To reduce the dew-point temperature of the conditioned space to a comfortable level, the occupant might temporarily reduce the dry-bulb temperature set point, causing the air conditioner to operate and "sweat out" (i.e., condense and remove) water from the air. This is disadvantageous in that the occupant must keep guessing at the dry-bulb temperature set point required to provide a comfortable environment. Furthermore, when the sensible load dominates at a later time and/or the occupant leaves the room without resetting the thermostat to a higher set point, the dry-bulb temperature of the air in the conditioned space is most certainly reduced to an uncomfortable level. Later, the occupant might raise the dry-bulb temperature set point, causing the heating plant to operate and raise the space dry-bulb temperature to a more comfortable level. Alternatively, the furnace might be locked OFF, and the increased dry-bulb temperature set point would prevent the heating plant from operating and thus result in a thermally uncomfortable environment within the space. This entire process is undesirable because it requires human intervention and is also inefficient from an energy viewpoint. Alternatively, the occupant would have to use a separate dehumidifier at additional cost (both capital and energy) and suffer the added inconvenience of noise and the need to empty the water from the unit.

Control systems consisting of a thermostat and a humidistat are currently available wherein both devices have equal-authority control over the ON/OFF status of the cooling plant. In such systems, either the thermostat (if the sensed dry-bulb temperature is above its set point) or the humidistat (if the sensed relative humidity is above its set point) can start the cooling plant. However, the cooling plant can be stopped if and only if both the thermostat and the humidistat are "satisfied" (i.e., both the sensed dry-bulb temperature and the sensed relative humidity are below their respective set points). It is important to note that the humidistat in such control mechanisms uses the air's relative humidity as the primary means for determining the plant's operating status, and therein lies the major drawback of such systems. The relative humidity of air will increase with decreasing dry-bulb temperature. Thus, when a cooling plant is being operated by the above-described equal-authority control system, the outcome, under the right conditions, is runaway system operation in that the cooling plant gets locked ON. With the cooling plant ON, the dry-bulb temperature decreases, resulting in an increase in the relative humidity, causing the humidistat to maintain an ON signal for the cooling plant and also inhibits the humidistat from being satisfied (even though the thermostat might be satisfied), and hence the cooling plant gets locked ON.

The above-mentioned problems, such as the need for manual intervention, overcooling of the conditioned space, runaway system operation from using equal-authority controllers, are eliminated by the innovative integrated temperature and humidity controller (ITHC)[1]. Until recently, attention has focused primarily on simulation efforts to develop and analyze the controller's operation and performance. Now, with the introduction of new products incorporating both a dry-bulb temperature sensor and a relative humidity sensor, the ITHC algorithms have been implemented in prototype units of the product to conduct brief and limited field tests to verify the operation and performance of the control algorithms. Even though the control algorithms were developed using a simulation model of a single-family house, they are believed to be equally valid for a wide range of HVAC systems and applications.

In the following, the simulation is discussed briefly, the ITHC block diagram is described, and the field test sites for which results are reported herein are summarized. This is followed by a discussion of the preliminary field test results and conclusions.

CONTROLLER DEVELOPMENT

Algorithms for the ITHC were designed and tested using the proprietary Generalized Engineering Modeling and Simulation (GEMS)[2] software tool. For the ITHC development, detailed dynamic simulation models of an actual single-family residential house and its HVAC components and systems were used along with typical hourly weather data (TMY/TRY format). The simulation models have previously been calibrated with actual metered energy consumption data for the house. Both the house and the simulation model have been used extensively for developing several innovative comfort control algorithms and for verifying the operation and performance of product prototypes using these new algorithms.

Until recently, the ITHC development efforts were focused primarily on design and development of the algorithms using detailed dynamic simulation models of an actual single-family home and its HVAC components and systems. The controller performance has been analyzed extensively using the proprietary GEMS software tool by conducting detailed dynamic simulations for typical days and for entire cooling seasons with hourly weather data for four U.S. cities: Houston, Texas, Miami, Florida, Minneapolis/St. Paul, Minnesota, and St. Louis, Missouri. Details on this development and simulation results will be published elsewhere in the near future.

THE INTEGRATED CONTROLLER

Figure 1 shows that the ITHC consists of a dry-bulb temperature sensor and a relative humidity sensor. The sensed dry-bulb temperature and the sensed relative humidity determine the sensed dew-point temperature in the conditioned space. The space occupant is required to enter two set points: the dry-bulb temperature set point and the relative humidity set point. These set points are then used to determine the space dew-point temperature set point. From these inputs, measurements, and calculations, the controller computes two temperature error signals: the dry-bulb temperature error and the dew-point temperature error. These errors are then compared and the numerically larger of the two is used in the classical proportional-integral-derivative (PID) control block, with an anticipation and a hysteretic switch, to generate the ON/OFF control signal for the cooling plant. Note that it is not mandatory to use the maximum of the two errors as an input to the PID block; rather, any desired functional relationship can be used to deliver an appropriate error signal to the PID block. One advantage of using the numerically larger value is that it is simple, and another advantage is that any step change in the errors, for example, due to a step change in the control set points, will be easily and almost instantaneously relayed to the PID block for a quick and robust response by the controller.

Note that the wet-bulb temperature, or any other absolute thermodynamic property of moist air, can be used by the controller in place of the dew-point temperature. Additionally, rather than computing the set-point value for the absolute thermodynamic property, provisions can be made for the space occupant to directly specify the desired set point for the absolute thermodynamic property of moist air (e.g., dew-point temperature, wet-bulb temperature). Several other such variations are possible.

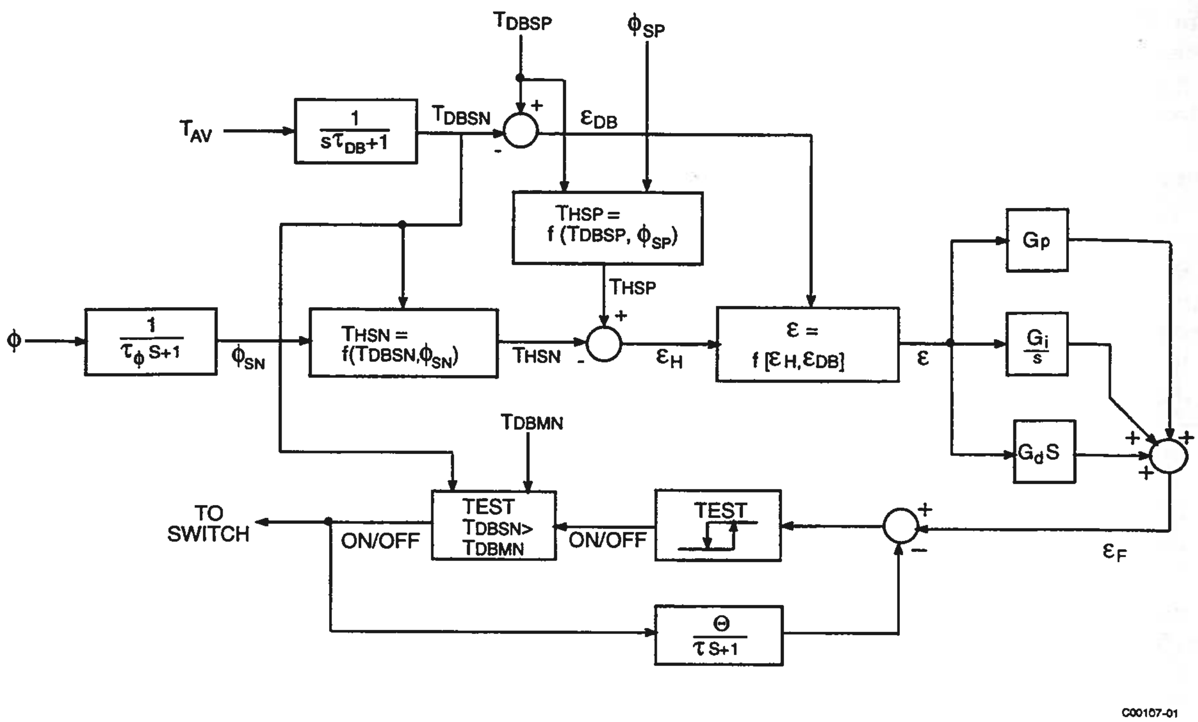

Figure 1. Block Diagram of the Integrated Temperature and Humidity Controller

FIELD TEST SITES

As previously mentioned, the ITHC algorithms were implemented in product prototypes, and field tests were conducted at several sites in two southern cities in the continental United States, as well as in Singapore. The results presented herein are from one of these sites, consisting of two adjacent unoccupied guest rooms in a hotel, each equipped with chilled-water fan coil units. The two, virtually identical adjacent rooms were selected primarily for comparing the operation and performance of the ITHC with that of a dry-bulb temperature controller (DBTC) under the exact same conditions (solar, outdoor temperature and humidity, internal loads, etc.). To obtain comparative results, the fan coil unit in one of the rooms was controlled by the ITHC algorithms in a product prototype and the fan coil unit in the other room was controlled by an identical product prototype with the humidity control mode disabled (i.e., a DBTC).

RESULTS AND CONCLUSIONS

As previously mentioned, the invented ITHC algorithm was implemented in a product prototype, and limited field tests were conducted. Preliminary results from one of these sites, described above, will now be presented and discussed. For these tests, the room set points were 77°F dry-bulb temperature and 45% relative humidity. These correspond to a dew-point temperature set point of about 54°F and position the state approximately in the middle of the ASHRAE thermal comfort zone for summer.[3, 4]

For the conditioned space under control of a conventional thermostat (i.e., DBTC), Figure 2 shows the outdoor and space dry-bulb and dew-point temperatures along with the ON/OFF status of the cooling plant (chilled-water fan coil unit and air blower). Note that during the hours between midnight and about 0900, the sensible thermal load on the room is relatively low, and thus the cooling plant operates intermittently in that the ON duration is shorter than the OFF time. This causes the dew-point temperature in the space to increase to about 56°F when the plant is OFF because the cooling plant is not being operated sufficiently to permit removal of water from the space air. After 0900 hours, the sensible thermal load on the space starts increasing, causing the cooling plant to operate more frequently and also to stay ON for a longer duration relative to its OFF time. This results in removal of both sensible and latent heat from the space, and hence the dew-point temperature within the space decreases while the dry-bulb temperature is maintained near its set point of 77°F. After 1800 hours, the sensible thermal load on the space is reduced, resulting in shorter ON times for the cooling plant. The space dew-point temperature therefore rises after 1800 hours. The oscillations in the space dry-bulb and dew-point temperatures are reflective of

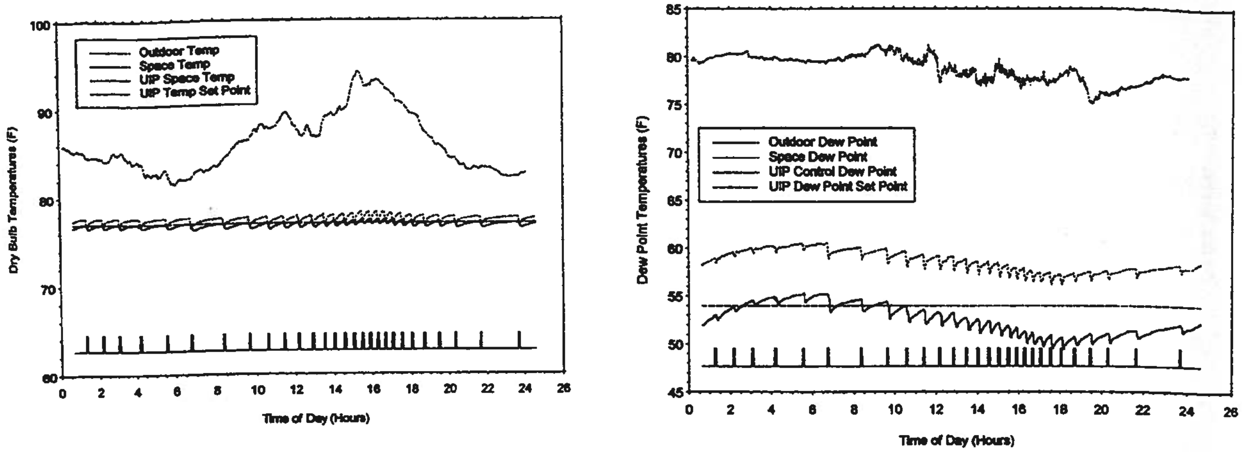

Figure 2. Space Conditions and Cooling Plant Status when Using a Conventional DBTC

the cooling plant cycling. The variations in the space dry-bulb temperature about the set point temperature are well within the thermostat's control band.

Note that during the entire day, the conventional DBTC fulfilled its prime objective of maintaining the space dry-bulb temperature near its specified set point of 77°F; however, the space dew-point temperature ranged from a low of about 50°F to a high of 56°F. Although the space dew-point temperature under this set of conditions is not excessively high, it is higher than the desired set point of 54°F. As shown in the following, this shortcoming of the conventional DBTC is overcome by the ITHC.

When the ITHC, in an adjacent room, is subjected to almost identical environmental and internal sensible and latent load conditions as applied to the conventional DBTC of Figure 2, the resulting dry-bulb and dew-point temperatures and the ON/OFF status of the air conditioner are as shown in Figure 3. Note that over the entire 24-hour period, the dry-bulb temperature within the conditioned space is maintained at or below the specified set point of 77°F and the dew-point temperature is maintained at or below its desired set point of 54°F. The oscillations in the space dry-bulb and dew-point temperatures are reflective of the cooling plant cycling. The variations in these temperatures about their respective set points are well within the thermostat's control band. Figure 3 shows that the ITHC provides significant improvement in the thermal environment and comfort for the occupant of the conditioned space.

The dry-bulb and dew-point temperature errors computed and used by the ITHC for controlling the cooling plant's ON/OFF status are shown in Figure 4. Close examination of the results in Figures 3 and 4 indicates the following control modes during this 24-hour day. Between midnight and 0700 hours, the sensible thermal load on the space is almost nonexistent; however the latent load reflected by the dew-point temperature is quite significant. This increase in the dew-point temperature results in the controller operating the cooling plant to maintain the dew-point temperature at or below its set point. As shown in Figure 3, the controller does an excellent job of this. As a consequence, the space dry-bulb temperature is reduced to about 73°F during this period. After 0700, the latent load on the space decreases and the sensible load increases. The cooling plant remains under dew-point control mode, albeit at low cycle rates, until about 1200 hours. Between 1200 and 1400 hours, both the sensible and latent loads on the space are such that the numerically larger of the dry-bulb and dew-point temperature errors is used for controlling the cooling plant status. After 1400 hours, the sensible load on the space is sufficiently high that the controller is in the dry-bulb temperature control mode. As reflected by the cooling plant cycle rate, the sensible load on the space increases until about 1700 hours, resulting in moisture removal from the space. From 1400 to 1700 hours, the space dry-bulb temperature is maintained at its set point and the dew-point temperature decreases. After 1700 hours, the sensible thermal load on the space decreases, resulting in fewer cycles of the cooling plant. Consequently, the space dew-point temperature increases, however, the increase in the dew-point temperature is not sufficient to gain control of the cooling plant, and the operating mode remains under dry-bulb temperature control.

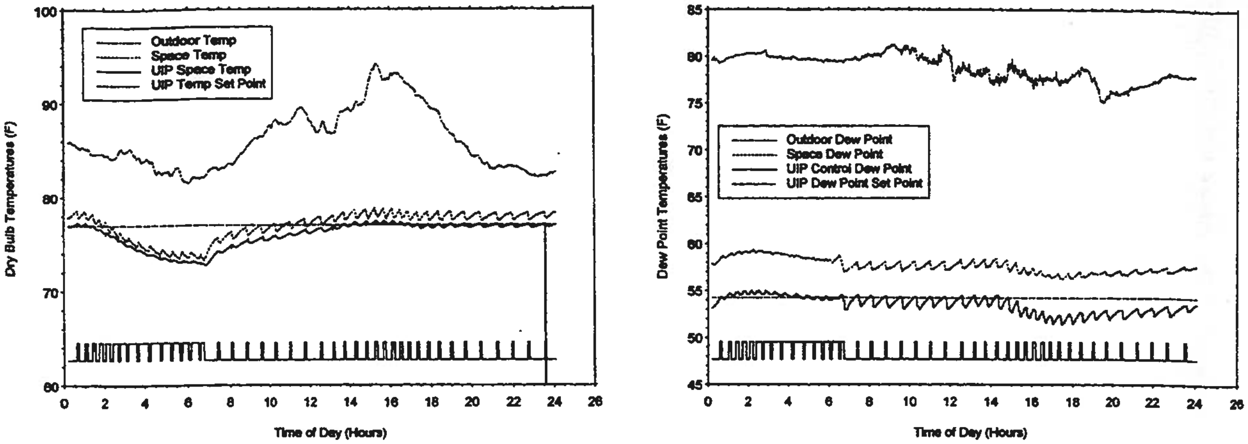

Figure 3. Space Conditions and Cooling Plant Status when Using the Integrated Temperature and Humidity Controller

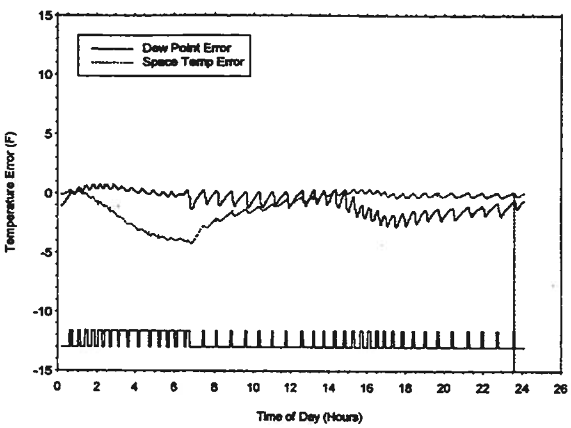

Figure 4. Temperature Errors Considered by the Integrated Temperature and Humidity Controller

As mentioned earlier, limited field tests have been completed. The results obtained to date are in agreement with those predicted by detailed dynamic simulations. Overall, the operation and performance of the innovative ITHC appears to be extremely robust and promising.

SUMMARY

Existing conventional thermostats control the ON/OFF status of a cooling plant to maintain the space dry-bulb temperature at or below the specified set point. Such controllers are ineffective at reacting to high humidity levels within the conditioned space, resulting in an uncomfortable thermal environment for the occupant. Consequently, the occupant must resort to measures such as manually lowering the space dry-bulb temperature set point to "sweat out" the water from the air. An innovative concept, the Integrated Temperature and Humidity Controller (ITHC), has been invented for controlling both the dry-bulb temperature and the absolute moisture content of the air in a conditioned space. These new algorithms, designed and developed using detailed dynamic simulations, have been implemented in a product prototype, and limited field tests have been completed. Preliminary results presented herein from two identical and adjacent guest rooms in a hotel confirm that the expected operation and performance of the controller and its robustness are extremely encouraging. The results show that the conventional dry-bulb temperature controller does not react to space dew-point temperatures increasing to above desired values. On the other hand, the ITHC robustly operates the cooling plant in such a way as to maintain both the dry-bulb temperature and the moisture content at or below their respective set points. This results in a relatively more comfortable thermal environment for the occupant. To date, results from the field tests are extremely promising.

REFERENCES

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